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September 19, 1991

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Ref: N00014-91-C-0148

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Enclosure: Quarterly Progress Report for June-September 1991 (R91-970089-01)

Subject: Loading and Vibration Reduction through Active Aerodynamic Control
Contract N00014-91-C-0148

Dear Sir or Madam:

Enclosed is the Progress Report for the reference contract for June-September 1991.

Very truly yours,

R. H. Schlinker

R. H. Schlinker,
Manager, Aeroacoustics
and Experimental Gas Dynamics

Enclosure

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Report: R91-970089-01
Date: September 13, 1991

Loading and Vibration Reduction Through Active Aerodynamic Control

R&D Status Report
13 June 1991 through 13 September 1991

PROGRAM CODE NO.:	z21j001---03/20 FEB 1991/1215
CONTRACTOR:	United Technologies Research Center
CONTRACT:	N000014-91-C-0148
CONTRACT AMOUNT:	$296,313, ($182,300 funded through April 30, 1992)
EFFECTIVE DATE OF CONTRACT:	June 13, 1991
EXPIRATION DATE OF CONTRACT:	December 31, 1992
PRINCIPAL INVESTIGATOR:	John C. Simonich
TELEPHONE NO.:	(203) 727-7821
SHORT TITLE OF WORK:	Loading and Vibration Reduction
REPORTING PERIOD:	13 June 1991 through 13 September 1991

PROGRAM DESCRIPTION

The objective of this work is to provide active aerodynamic control concepts for reducing propulsor blade unsteady lift and moments. These unsteady forces are responsible for vibration and noise during an encounter with an incident gust. This effort represents an extension of a recent UTRC breakthrough in which active aerodynamic control was used to reduce *noise* generated during a two dimensional (2-D) blade-gust interaction. The associated reductions in unsteady blade surface pressures responsible for the noise reduction will be evaluated under the current program. Also, an analytical effort will generate a computer code for predicting surface pressures created by an actively controlled flap system and will estimate the required flap motion to cancel the unsteady lift. This work will extend the UTRC 2-D expertise in active aerodynamic control to a three dimensional (3-D) capability. This will be done by analytically investigating the effect of a swept gust interacting with an actively controlled, segmented flap to control the bending moment as well as the lift. Also, an exploratory experimental study on the effects of a swept gust encountering a 2-D non-segmented flap will be performed. In summary, this study will provide the Navy with concepts for active aerodynamic control for reducing unsteady blade loads responsible for structural vibration.

DESCRIPTION OF PROGRESS

1. EXPERIMENTAL CONFIGURATION

Design of the new test configuration relevant to the current contract goals has been started in the UTRC Design department. Three modifications to the existing UTRC Interaction Facility are needed to conduct the planned experimental studies. The first is the increase of the blade passage frequency of the gust generator to achieve a normalized blade passage frequency ($\omega b/U$) of unity. Fourteen additional tapered rods will be fabricated and the current gust generator hub with two rods will be modified to accept a total of 16 rods. Secondly, in order to investigate the effect of wake skewing into the two-dimensional actuated vane, a new hub to contain two swept rods is being designed. Two new swept rods will be mounted in the new hub, skewed at a 30° angle to the radial direction.

The final modification to the UTRC interaction facility addresses the need to measure the total unsteady lift on the vane during the wake/vane interaction both with and without active control applied. Two meetings were held at UTRC with personnel from the Applied Research Labs at Penn State to discuss methods for measuring unsteady forces and moments. Attending the first meeting on August 8, 1991 were C. Burroughs (ARL), K. Dreitlein (UTRC), D. Hanson (Hamilton Standard), P. Lavrich (UTRC), R. Schlinker (UTRC), J. Simonich (UTRC), and W. Zierke (ARL). C. Burroughs presented a review of experimental techniques used at ARL to measure unsteady forces and lift. Preliminary plans were discussed for a scheme to use at UTRC for unsteady force and moment measurement. A subsequent meeting was held at UTRC on August 26, 1991 to finalize the measurement concept as it applies to the UTRC Interaction Facility. Attending the second meeting were C. Burroughs (ARL), W. Nuss (ARL) and J. Simonich (UTRC). A design concept which was acceptable to both parties was approved. Since ARL is very interested in measuring both twisting and bending moments, the vane will be mounted with four force transducers. Various sums and differences of the four transducers can

be used in the experimental study to determine the unsteady lift and moments. For the current funded contract effort, only unsteady vane lift data will be acquired, analyzed, compared with predictions and reported. The vane mounting scheme is currently developed by the UTRC design room.

In order to reduce the sidewall boundary layer contamination on the flow over the two dimensional vane in the test section, a slot is being machined into both sidewalls between the gust generator and the airfoil so that a boundary layer suction system can be installed. Evidence of the influence that the sidewall boundary layers have on the two dimensionality of the data is discussed below.

2. EXPERIMENTATION

Surface Unsteady Pressure Measurements

One of the objectives of the current work is to measure the unsteady surface pressures on the vane during gust encounters both with and without trailing edge flap actuation. This local pressure information can be integrated to obtain an unsteady lift component which can be compared to the direct measurement of unsteady lift (which will be obtained from the force transducers) as well as the predicted values. The conventional experimental technique used to measure unsteady surface pressures is to flush mount miniature pressure transducers in the airfoil along the chord. While this generally yields high quality results, it is physically impossible in the current study due to size constraints and prohibitive costs to install a sufficient number of transducers to obtain an accurate measure of the integrated pressures. An alternate method to obtain high spatial resolution unsteady pressure measurements has therefore been devised.

Figure 1 shows the alternate method which is based on traversing a single pressure transducer along the airfoil sidewall to measure the unsteady pressure as a function of position. A slot is cut in the sidewall at the airfoil/sidewall junction and a fast response pressure transducer is moved along the slot in small spatial increments using a stepping motor traverse system. The slot is closed in front and behind the transducer with a cover plate to avoid flow leakage. A test was conducted to verify that the unsteady surface pressures measured on the sidewall are the same as those measured on the airfoil surface at mid-span. Both transducers were mounted at a 10% chord location. Data was synchronously averaged over 100 rotor revolutions. A comparison of voltages from two identical transducers is shown in Figure 2. The shape and levels of the unsteady signals are very similar. The transducer in the sidewall has more noise associated with it but this may be expected since it is in the turbulence of the sidewall boundary layer. The offset between the two levels is shown as measured. This difference in DC level is discussed below in the section entitled *Test Section Uniformity*.

A preliminary test was performed to determine whether or not a sidewall mounted pressure transducer would be able to accurately measure the 2-D unsteady surface pressure of the vane. In a preliminary test prior to machining the sidewall slot, gust synchronized unsteady pressure measurements were made at discrete locations along the airfoil/sidewall junction by flush mounting an 1/8th inch diameter microphone at seven chord-wise stations in holes in the sidewall. The results are shown in Figure 3. As expected, the unsteady surface pressure is highest near the leading edge of the airfoil. The unsteady pressure amplitudes drop considerably

downstream of 50% chord. There is an interesting double peak in the pressure trace at the 4.2% chord location which may be caused by local flow separation at the leading edge induced by the flow angle change caused by the gust from the rod wakes.

A test was conducted to determine if the magnitude of flap actuation available in the current system was sufficient to counter the unsteady surface pressure caused by the rod wakes. A high response pressure transducer was mounted in the airfoil at a 10% chord location. The flap was programmed to provide the most impulsive actuation possible within the frequency response limits of the servo motor system. The flap position versus time profile chosen was a 1-cosine function (the flap starts and finishes at 0° flap angle). This profile was found in previous acoustic work at UTRC to work well to eliminate acoustic dipole pulses. The delay time between the once per revolution signal from the gust generator and the start of flap actuation was set so that the actuation would occur during a period of relative calm between the two rod wake gust passages. This was done so that the amplitude and shape of the flap actuation pressure pulse could be directly compared to the pressure pulses generated by the rod wakes. The result is shown in Figure 4. The peak amplitude caused by the flap actuation was nearly half the peak amplitude of the rod wake pressure pulse. The flap actuation pulse rises rapidly, but drops off slower with a long tail. Since ARL is mainly interested in reducing harmonics of blade passage, the flap system appears to have enough power and quick enough response to have an effect but may not be large enough to completely cancel the pressure.

Test Section Uniformity

To ensure a two dimensional flow over the vane to simplify the analysis of the data and keep the active control problem tractable, the span-wise uniformity of the test section was checked by several methods. First, the steady state flow was examined using fluorescent paint to visualize the limiting streamlines on the airfoil surface. A photograph of the airfoil surface flow visualization is shown in Figure 5. The flow along the centerline was nominally two-dimensional, but on either side of the center the flow is seen to move away from the sidewalls. The flap, which was held stationary for this test, is identified by the vertical line on the right hand side of the picture. The vertical line extending half way down the airfoil was the previously described slot used for mounting the high response pressure transducer at 10% chord. The surface around the slot was filled with wax and smoothed.

In the second method for determining how the unsteady pressure varies across the span of the airfoil, the high response pressure transducer was positioned at various stations along a span-wise slot at the 10% chord location. Results of the pressure surveys from 16 to 50% of the span are shown in Figure 6. This data was synchronously averaged over 100 rotor revolutions. The average value of each trace was subtracted from each point, in effect an "AC" coupling of the signal. The shapes and peak amplitudes of the signals in general are very similar. The data taken at 29.2% span has a smaller peak and the data from 16.7% span has boundary layer turbulence noise associated with it. The background, absolute "DC" levels of the pressure taken from the average of the signals in Figure 6 are shown plotted as a function of span in Figure 7. Outboard of 25% span, the levels are more or less constant, indicating a uniform test section flow in this region. In contrast, the pressure at the 16.7% span station is clearly higher, caused by the sidewall boundary layer or some other unexplained source. Further investigation of this phenomenon will continue. This data should be viewed with some caution as there is some

measurement error associated with positioning the unsteady pressure transducer so that it is flush with the surface and so that there are no surface irregularities near the pressure tap location.

The third method used for examining the test section uniformity utilized hot wire measurements. Three dimensional, ensemble averaged, synchronized velocity measurements were made of the wakes downstream of the gust generator rods. The measurements were acquired earlier by UTRC using the slant wire technique. A 100 point ensemble average was acquired at 0.5 inch increments across the span at the quarter chord location of the vane to check the two dimensionality of the gust wake. (The vane was removed during these measurements.) In order to examine the teste section uniformity, the average free-stream axial velocity component was obtained by averaging the data between the wake gusts. The analysis of this data results in a coarse span-wise axial velocity survey which is shown in Figure 8. The inner two thirds of the span are uniform, but the boundary layer on the sidewall occupies nearly 20% of the span. This thick boundary layer may be caused by the flow separating off the sharp opening for the gust generator just upstream of the test section. An attempt will be made to minimize this effect by applying suction to the sidewalls downstream of the gust generator and just upstream of the airfoil.

CHANGE IN KEY PERSONNEL

No changes in key personnel have occurred.

SUMMARY OF SUBSTANTIVE INFORMATION DERIVED FROM SPECIAL EVENTS

As mentioned above, a meeting was held at UTRC on August 8, 1991 between ARL and UTRC to discuss the goals of the current contract and how they fit into ARL's plans for this technology. A review of the UTRC background in active aerodynamic control was given by J. Simonich. W. Zierke presented an overview of the ARL Penn Sate Program for DARPA in flow and force control. The high Reynolds number pump (HIREP) facility at ARL was described with a view towards installing some variation of the current actuated trailing edge flap concept on an ARL propulsor model.

PROBLEMS ENCOUNTERED AND/OR ANTICIPATED

No problems have been encountered, and no problems are anticipated.

ACTION REQUIRED BY THE GOVERNMENT

No action is required by the government.

FISCAL STATUS

(1) Amount currently provided on contract:	$182,300[1]
(2) Expenditures and commitments to date:	$ 9,485
(3) Funds required to complete work:	$286,828[2]

J. C. Simonich

R. H. Schlinker

[1] Current funding through April 30, 1992..

[2] Assuming full contract award of $296,313 for work through December 31, 1992.

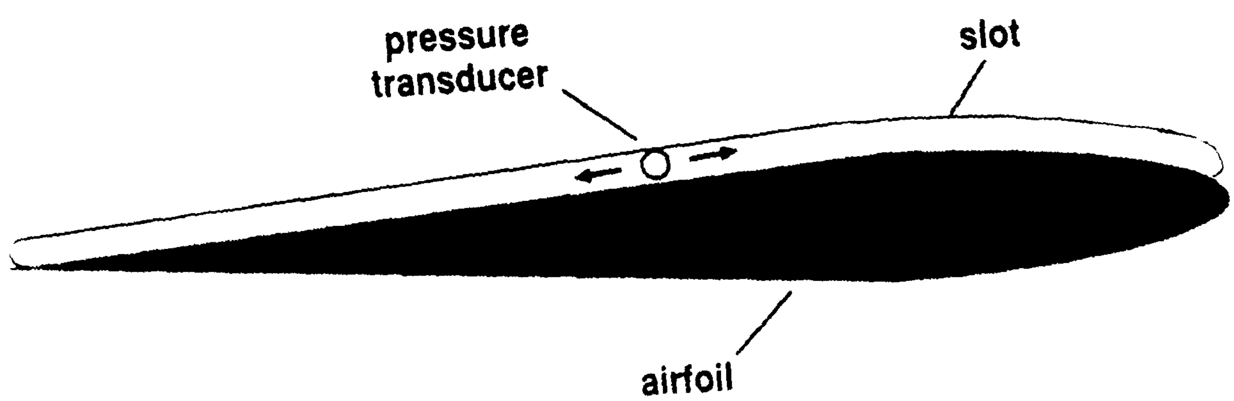

Figure 1 - High Spatial Resolution Unsteady Pressure Measurement Technique

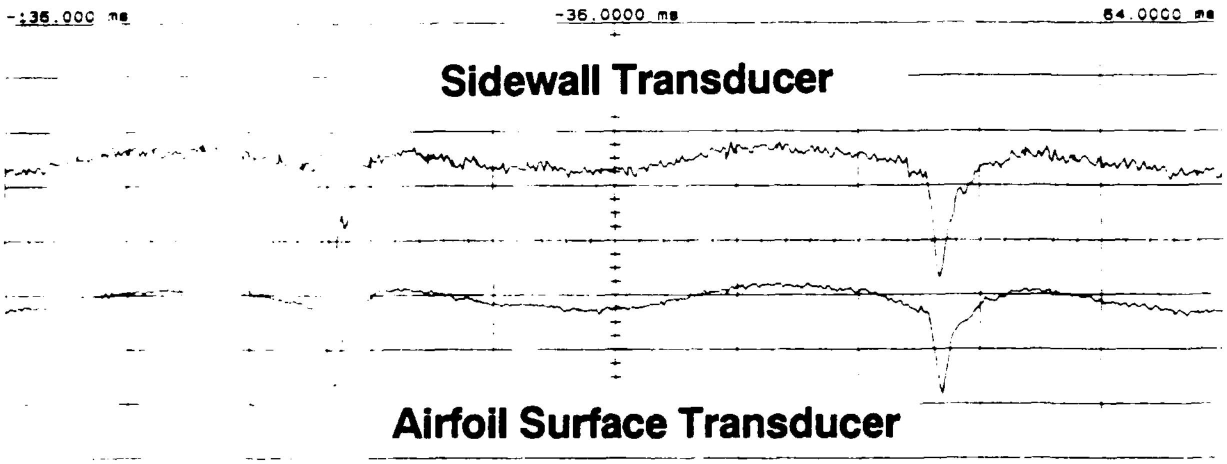

Figure 2 - Comparison of Sidewall and Airfoil Mounted Pressure Transducers

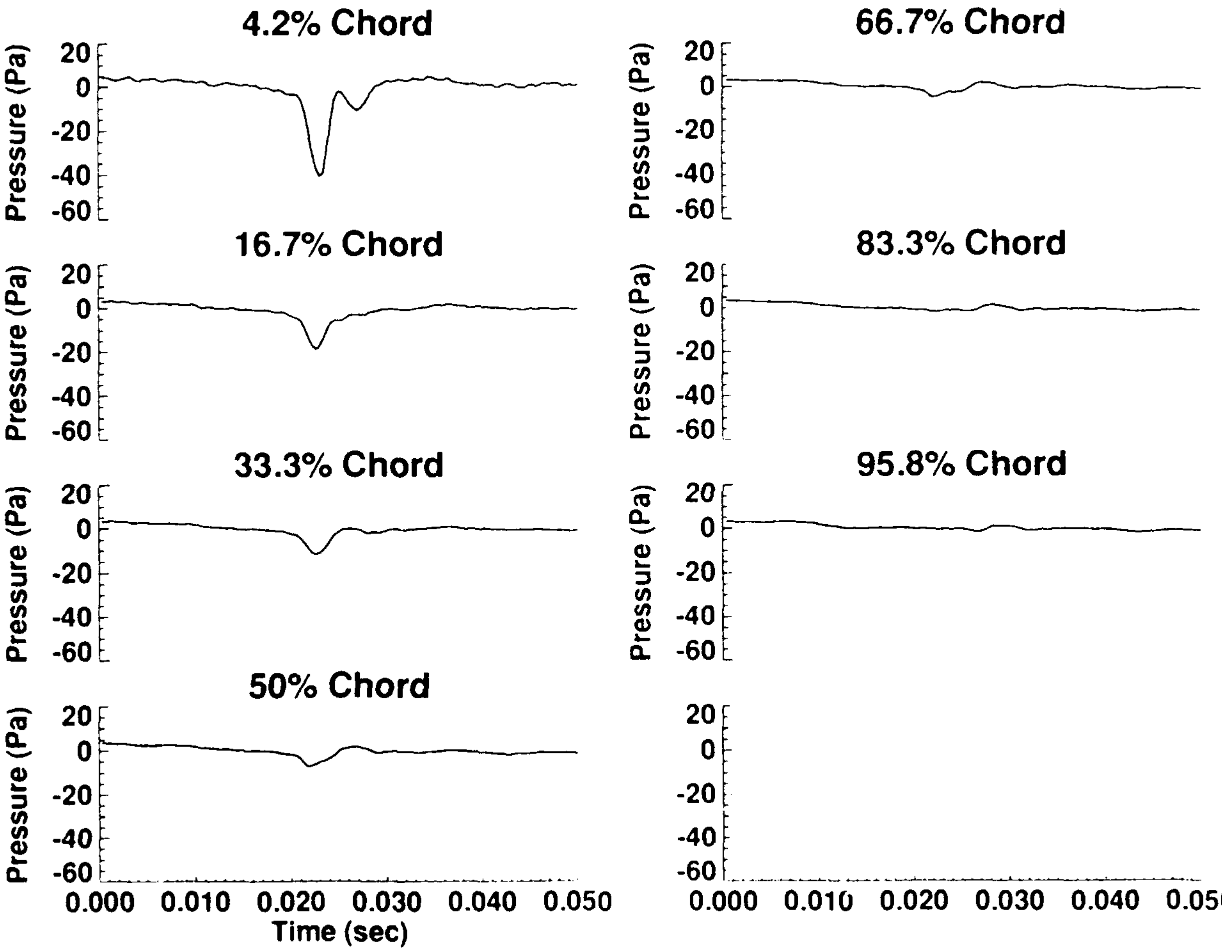

Figure 3 - Unsteady Pressure as a Function of Chord for NACA0009 Airfoil

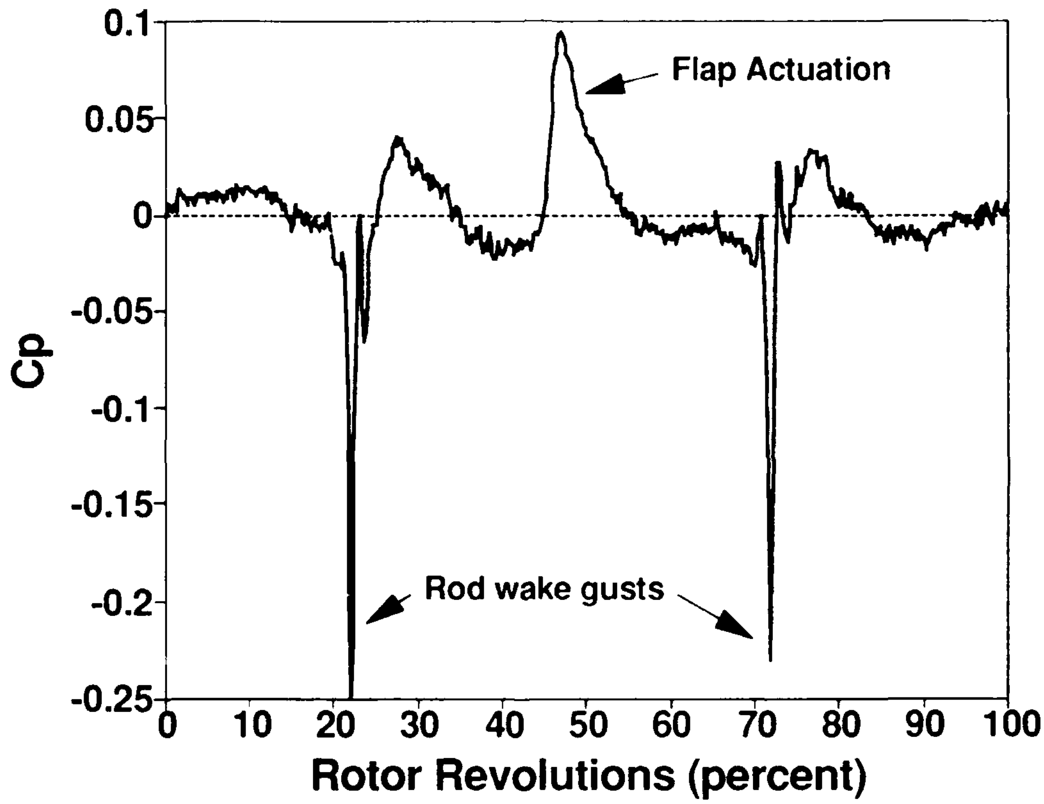

Figure 4 - Gust Synchronized Unsteady Pressure at 10% Chord with Trailing Edge Flap Actuation

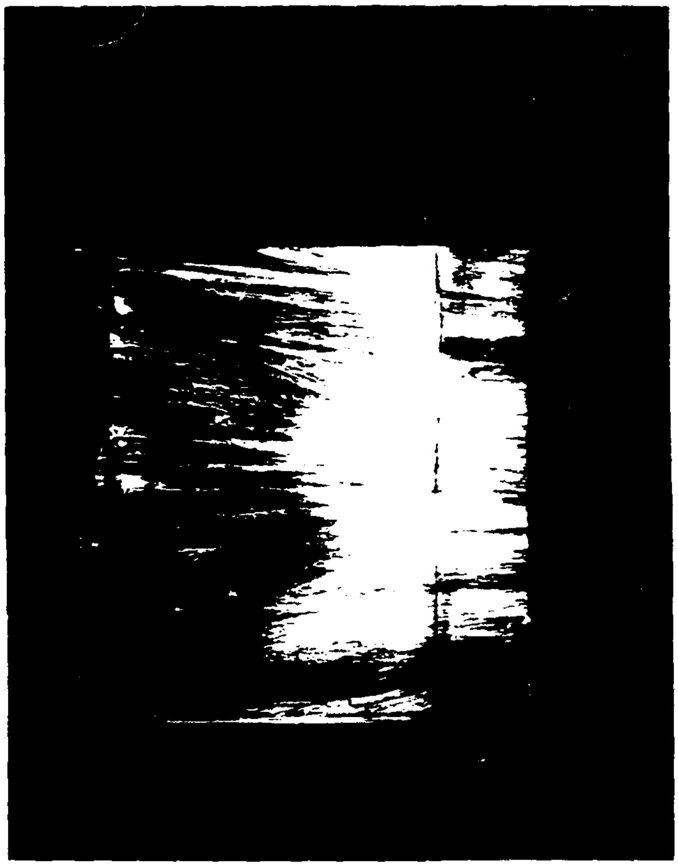

Figure 5 - **Fluorescent Oil Surface Flow** Visualization of NACA 0009 Airfoil (flow from left to right)

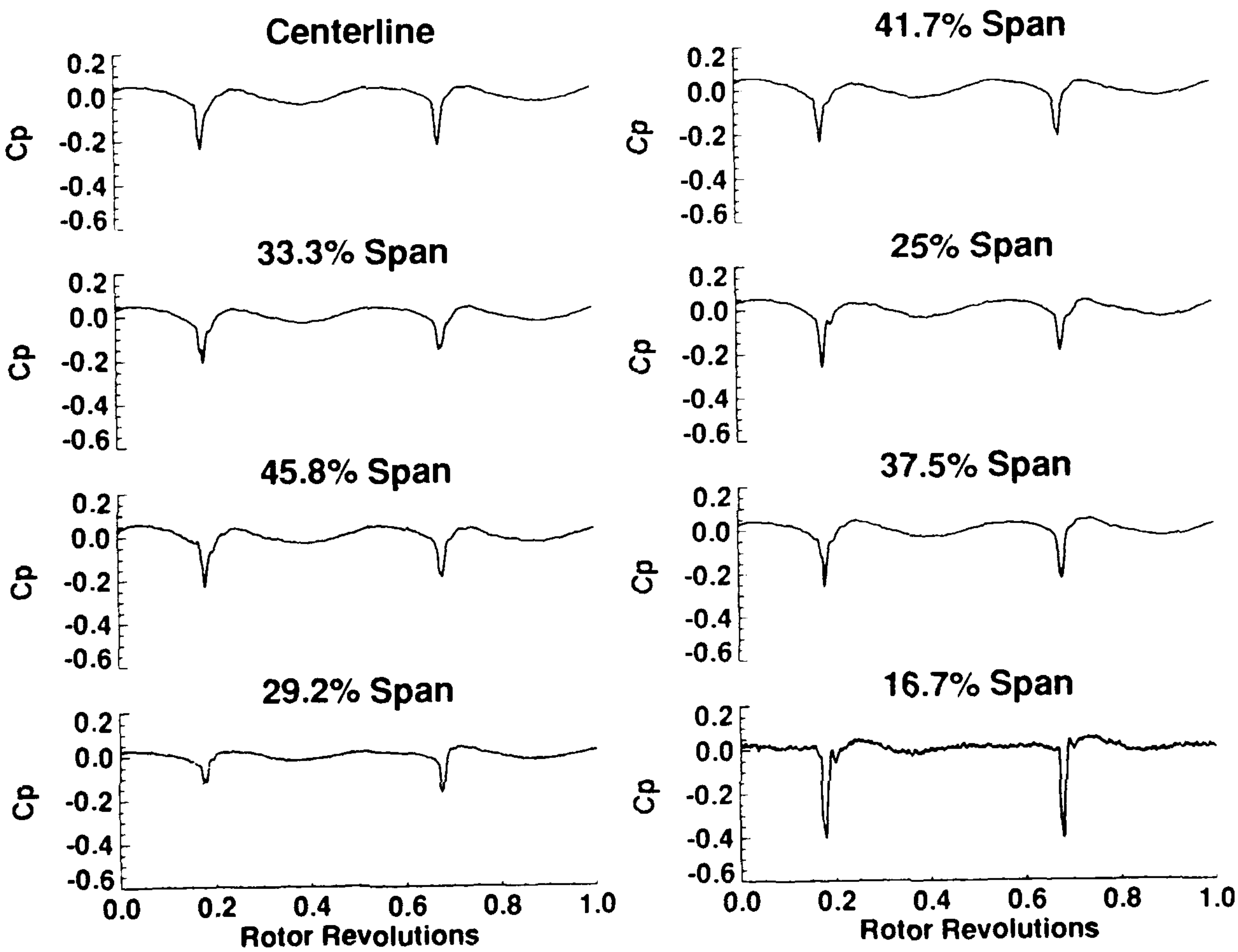

Figure 6 - Spanwise Variation of Unsteady Surface Pressure of NACA 0009 Airfoil at 10% Chord

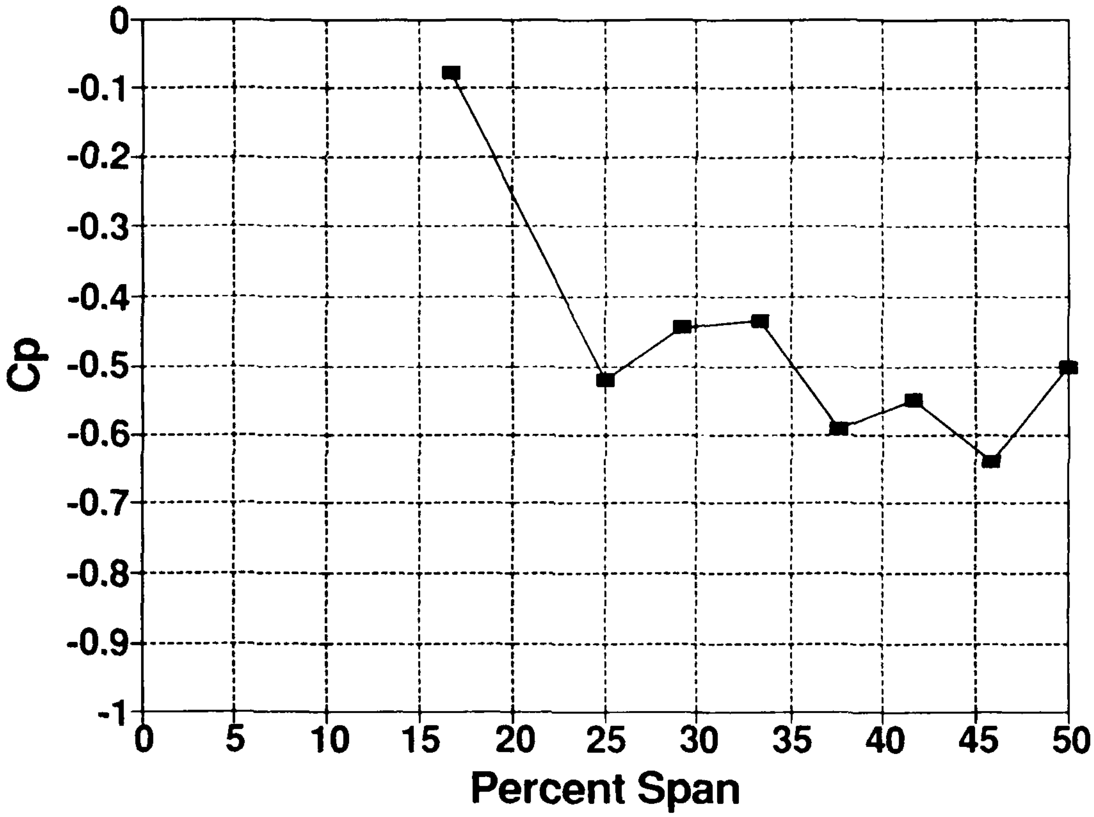

Figure 7 - Spanwise Variation of Average Surface Pressure of NACA 0009 Airfoil at 10% Chord

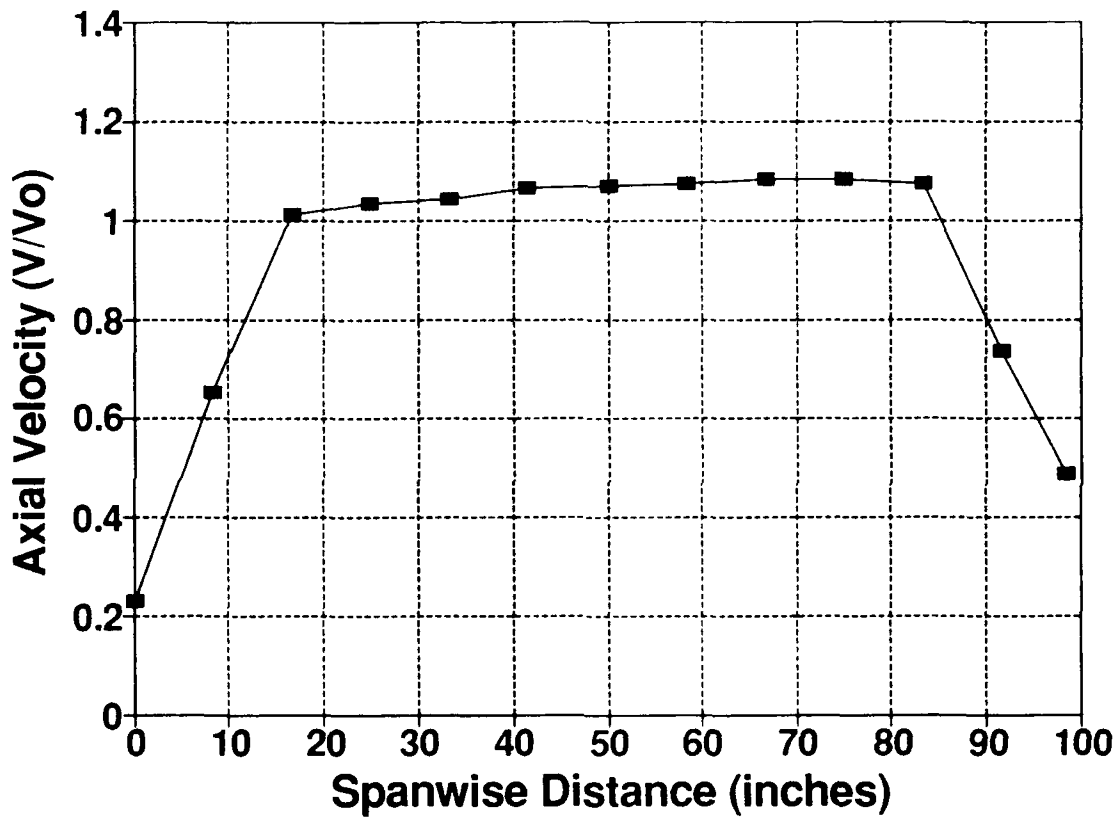

Figure 8 - Spanwise Velocity Variation of Test Section at Quarter Chord Location (airfoil removed)